UNIVERSITI PUTRA MALAYSIA

A STUDY OF IN-SITU L-CONNECTIONS FOR PRECAST CONCRETE SANDWICH PANEL BUILDING SYSTEM

PANG SIAW CHIN

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By

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Chairman: Professor D. N. Trikha, Ph.D.

Faculty: Engineering

A number of fifty four specimens have been tested in order to investigate the strength and behaviour of cast-in-situ right angle vertical connections between two precast concrete sandwich panels (PCSP) under pure moment and shearing force separately. Four types of connections have been chosen for study, namely connection types A, B C and D, defined by the length of the anchor steel bars in the connection area, being respectively 105mm, 190mm, 285mm and 289mm. Three different spacings of ASB in the connections, viz. 100mm, 200mm and 300mm have been attempted for each connection type.

For both pure moment and shearing force tests, the forces are increased gradually till the specimens fail. In the pure moment tests, the deformations of the specimens including the change of the included angle, the concrete surface strains and the strains in the anchor steel bar have been recorded, whereas for the shearing force tests, only the shear displacements of the specimens have been recorded.

Structural behaviour of the connections in flexure has been observed for each type of connection in regards to its strength, ductility and rigidity. Connection type D is found, amongst the four types studied, to have the highest strength and ductility.

For ultimate moment capacity, connection types B, C and D have at least 25%, 68% and 80% higher capacity than that for type A; whereas first crack moments for connection types B, C and D are respectively 53.2%, 72.6% and 84.1% higher than the first crack moment for type A. Moment versus change of the included angle curves show that connection type D exhibits the highest ductility compared to other connection types. All connection types show high degree of reserve deformability and degree of rigidity, which at least 2.55 and 0.95 respectively. Nevertheless, the failure crack patterns for all connection types in flexure are similar.

In the shear tests, all connection types except type A failed in excessive shear displacement. However, similar shear strengths have been observed for all the connection types. All connection types exhibit brittle behaviour under shearing force. However, connection type D shows higher rigidity than others, where its ultimate shear displacement being less than 1.0mm.

For all specimens tested either under moment or shearing force, construction joint between the precast concrete sandwich panel and the cast-in-situ connection was the critical zone, all the specimens failed due to excessive deformation in this zone.

Connection type D is recommended as a suitable vertical L-connection due to its outstanding strength and superior structural behaviour under the action of both moment and shearing force. The usual reinforced concrete theory gives good estimates of the ultimate moment capacities of the joint, but a coefficient 0.6 is suggested for design to ensure the serviceability requirement of the connection. Formulas recommended by ACI-83 and BS8110-85 give accurate estimates to the ultimate shear strength of connection type D, however, a coefficient 0.7 is suggested to satisfy the serviceability requirement.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malasia sebagai memenuhi keperluan untuk ijazah Master Sains

SATU PENGAJIAN BAGI IN-SITU KONKRIT L-PENYAMBUNGAN UNTUK SISTEM PERUMAHAN 'PRECAST CONCRETE SANDWICH PANEL'

By

PANG SIAW CHIN

Mei 2002

Pengurusi: Professor D. N. Trikha, Ph.D.

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Sejumlah lima puluh empat specimen telah dikaji untuk menyiasat kekuatan dan sifat-sifat penyambungan tegak 90 darjah bagi dua keping "Precast Concrete Sandwich Panel" semasa dikenakan dengan daya momen dan daya ricih. Empat jenis penyambungan yang telah disiasat, dinamakan penyambungan jenis A, B, C dan D, dengan perbezaan panjang besi tetulang dalam penyambungan, 105mm, 190mm, 285mm dan 289mm masing-masing. Tiga jenis jarak besi tetulang dalam penyambungan 100mm, 200mm dan 300mm, untuk setiap jenis penyambungan telah disediakan.

Untuk kedua-dua jenis kajian, daya momen dan daya ricih ditambah secara perlahan sehingga spesimen gagal. Bagi kajian daya momen, sifa-sifat spesimen seperti perubahan sudut dalaman, terikan permukaan konkrit dan terikan besi tetulang telah dicatatkan. Manakala bagi kajian daya ricih, hanya perubahan ricih telah dicatatkan.

Sifat-sifat berlainan bagi setiap jenis penyambungan yang dikaji dengan daya momen telah diperhatikan termasuk ketuatan, kekukuhan dan keketatan. Penyambungan jenis D didapati menpuyai kekuatan dan kekukuhan yang paling

tinggi. Bagi daya momen muktamad, penyambungan jenis B, C dan D adalah 25%, 68% dan 80% lebih tiggi daripada jenis A; manakala bagi momen 'first crack', penyambungan jenis B, C dan D adalah 53.2%, 72.6% dan 84.1% lebih tiggi daripada jenis A. Graph daya momen lawan perubahan sudut dalaman menujukkan penyambungan jenis D mempunyai kekukuhan yang lebih tinggi daripada penyambungan jenis lain. Semua jenis penyambungan menujukkan kadar kebolehan perubahan bentuk dan kadar keteguran yang tinggi, iaitu lebih daripada 2.55 dan 0.95 masing-masing. Walaubagaimana pun, bentuk kegagalan bagi semua jenis penyambungan adalah sama.

Untuk ujian daya ricih, kecuali penyambungan jenis A, semua jenis penyambungan didapati gagal dengan perubahan ricih yang terlalu besar. Semua jenis penyambungan didapati bersifat "brittle". Kekuatan ricih untuk semua jenis penyambungan didapati sama, tetapi penyambungan jenis D didapati mempunyai keketatan yang paling tinggi, iaitu perubahan ricih muktamad kurang daripada 1.0mm.

Oleh sebab kekuatan momen dan ricih yang tinggi dan sifat-sifat yang baik, penyambungan jenis D adalah digalakkan penggunaan. Teori konkrit bertetulang besi telah dibukti memberi ramalan yang betul untuk kekuatan momen bagi semua jenis pemyambungan, tetapi parameter 0.6 adalah didapati sesuai untuk didarah dengan kekuatan momen untuk memastikan penyambungan berfungsi dengan baik. Formula yang tercatat dalam ACI-83 dan BS8110-85 didapati pula memberi ramalan yang baik untuk kekuatan ricih. Walau bagaimanapun, untuk memastikan penyambungan jenis D berfungsi baik, parameter 0.7 adalah dinasihatakn didarah kepada kekuatan ricih yang diperolehi dengan kedua-dua formula itu.

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Finally, I would like to thank those, who have helped me directly or indirectly in my study

PANG SIAW CHIN

I certify that an Examination Committee has met on 28th May 2002 to conduct the final examination of Pang Siaw Chin on his Master of Science thesis entitled "A Study of In-Situ L-Connections for Precast Concrete Sandwich Panel Building System" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (higher Degree) Regulation 1981. The committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotation and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

Pang Siaw Chin
Date: 7/8/02

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ASB	Anchor steel bar
D_{rs}	Degree of reserve strength
D_{rd}	Degree of reserve deformability
D_{srs}	Degree of shear reserve strength
D_{rsd}	Degree of reserve shear deformability
d_u	Ultimate shear displacement
f_{bu}	Ultimate bond stress
f_m	Maximum tensile stress in ASB
f_s	Stress in ASB
M'_u	Computed Ultimate Moment
M_u	Ultimate moment
M_{cr}	First crack moment
PCSP	Precast concrete sandwich panel
R_{cr}	Rigidity at first crack moment
R_u	Rigidity at ultimate stage
V_u	Ultimate shear force
$V_{0.3}$	Shear force corresponding to 0.3mm shear displacement
ε_{cs}	Concrete surface strain
ε_s	Tensile strain in ASB
ε_u	Ultimate tensile strain in ASB
ϕ	Change of included angle
p	Steel ratio
θ	Included angle
θ_o	Original included angle
θ_{cr}	Included angle corresponding to first crack moment
θ_u	Included angle at ultimate stage

CHAPTER I

INTRODUCTION

1.1 Introduction

This chapter briefly introduces the background of the research and out-line of the thesis. The objective and scope of the research are defined clearly, to orientate the research that has been carried out in the present study

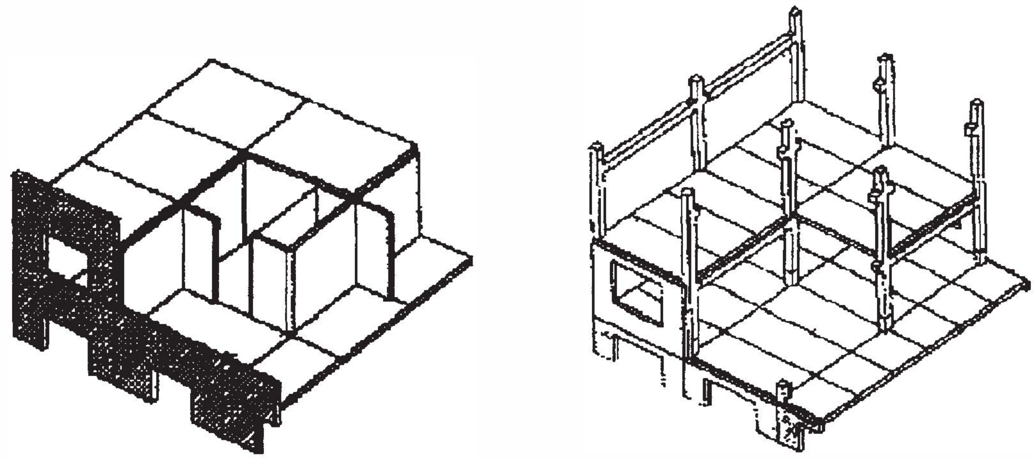
1.2 An Overview

Nowadays, there are two types of construction methods, which are the conventional cast-in-situ method and the precast method. In the conventional cast-in-situ method, the structural elements are cast at the final position in the structure; whereas, in the precast method, the structural elements are cast separately at another places before they are fabricated and installed at the desired position.

Precast method has increasingly become popular compared to the conventional cast-in-situ method due to its fast speed, high quality and wide range of architectural finishes. Precast method possesses all of these advantages because the precast concrete elements are manufactured under a controlled environment. Due to the demand of fast construction, especially after the Second World War, precast concrete elements have been industrialized and several industrialized building systems have been developed. One of the industrialized building systems (IBS) is a load-bearing wall system using the precast concrete sandwich panels (PCSP).

1.2.1 Precast Structural System

The building structural systems are mainly categorized into load bearing wall structure system (Figure 1.1(a)), and frame and skeletal structure system (Figure 1.1(b)). The structural elements of load-bearing wall structure systems consist of load-bearing walls and floors. However, the structural elements of frame and skeletal structure systems consist of columns, beams and floors. Due to the inherent nature of the structural system properties, the frame and skeletal structure systems offer a higher degree of flexibility of the space than the load-bearing wall structure systems. Thus, the frame and skeletal structure systems are utilized mainly for industrial buildings, shopping malls, car parks, sporting facilities and office buildings, whereas the load-bearing wall structures are suitable for apartment buildings, nursing homes, dormitories, hotels, etc. In an attempt to develop an economic residential building, load-bearing wall system using PCSP has been chosen for the present study.



(a) Beanng-wall Structure (b) Frame and skeletal Structure

Figure 1.1: Precast Structure Systems (Bohdan, 1966)

1.2.2 Precast Concrete Sandwich Panel (PCSP)

Collins (1954) defines the PCSP as the panel, which consists of two layers of relatively thin, high-density materials bonded to a core of relatively thick, low-density material. The function of the core is to split away the two layers of high-density materials, hence to provide a higher stiffness factor. However, the PCSP owns a higher thermal insulation due to the lower thermal conductivity material of the core. Thus, PCSP is a lighter, stronger and more insulated wall.

PCI Committee Report (1997) has presented various types of PCSP. Expanded polystyrene and polyurethane, which exhibit high thermal insulation, low strength and low density, are commonly used as insulation layers. The concrete wythe may be divided into structural or non-structural wythe. However, shear connectors are mainly categorized as concentrated shear connectors, continuous shear connectors and non-shear connectors. One of the most preferred PCSP is shown in Figure 1.2.

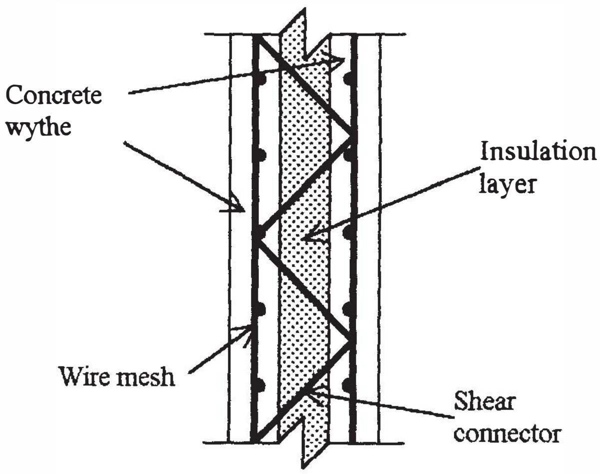


Figure 1.2: Precast Concrete Sandwich Panel with Its Components

1.2.3 Important Aspects in Precast Construction Method

As mentioned by Elliot (1994), there are four main aspects to be considered at the preliminary design stage of a precast structure, namely

i) Structural form,

ii) Frame stability and robustness

iii) Component selection

iv) Connection design

All these aspects are interrelated and should be dealt with simultaneously and interactively. These aspects for any construction solution should therefore be understood thoroughly before the construction solution is attempted.

Stability and robustness of a building are very important and are achieved through the integrity of the building. Therefore, having good connections between the structural elements are very important in integrating the structural elements in the building.

The reinforcement for the building constructed by conventional cast in-situ method is continuous throughout the entire structure. Therefore, it has sufficient stability and robustness. But due to the inherent nature of the precast components, the reinforcement from a precast component cannot extend into another precast component. This phenomenon emphasises the role of the suitable connection between the precast elements in aspects of stability and robustness of the building. As stated by Huyghe and Bruggeling (1991), " prefabrication does not mean to 'cut' the already designed concrete structure into manageable pieces..." Therefore all aspects in components design and structural stability should be dealt with simultaneously in the designer's mind.

1.2.4 Type of Connection in The Load-bearing Wall Structure

In the precast wall load bearing structure, there is only panel-panel connection, such as wall-floor, wall-roof and wall-wall etc. The panel-panel connections can be categorized as horizontal connections and vertical connections. The wall-floor and wall-roof connections are the horizontal connections. However, the connections between the wall panels in the same flour are the vertical connections The vertical wall-wall connections may be further divided into L-connections, T-connections and X-connections as shown in Figure 1.3.

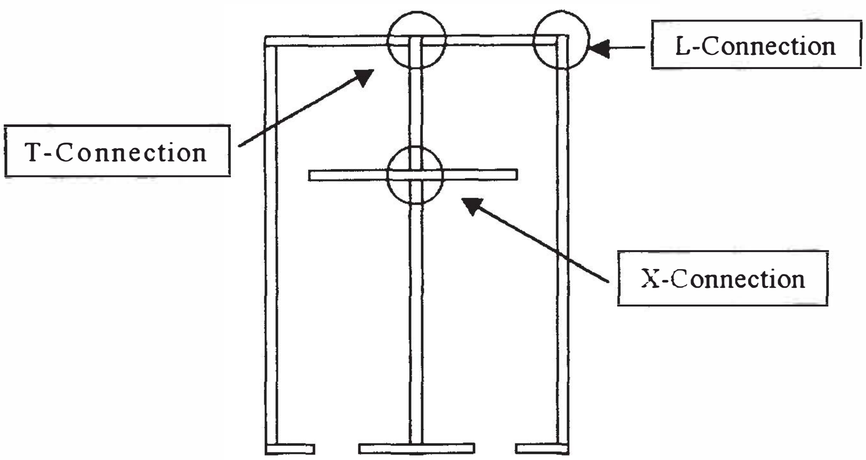


Figure 1.3: Plan Of Typical Precast Load Bearing Wall Structure

1.2.5 Connection Methods for Precast Elements

Basically, precast elements can be connected by cast-in-situ methods and mechanical means (Figure 1.4). The cast-in-situ methods offer a simple connection while the mechanical procedures offer fast speed but complicated connections. Most precast structure designers recommend the cast-in-situ method of connections, as the connections are more efficient and probably economical compared to the mechanical connections.

A cast-in-situ connection is designed by using the usual principles of reinforced concrete. Nevertheless, previous research results indicate that the connections do not behave as expected. The distress in precast structure may result from the lack of understanding of the behaviour of the connections under the design loads in service.